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# Advanced Multimode Radio for Wireless & Mobile Broadband Communication

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**Abstract**—Distributed base station architectures represent the new trend that operators follow in order to resolve cost, performance and efficiency challenges when deploying 4G networks. Main components of such architectures are multimode radios capable of operating according to GSM, HSPA, WiMAX and LTE standards, known as remote radio heads (RRH). The key feature of remote radio heads is the extended software configurability which enables the deployment of more flexible and energy-efficient radio solutions. This paper describes a modern multi-mode radio system reference architecture and the major digital building blocks that when combined together enable multi-mode and more power efficient operation. It concentrates on blocks which can efficiently run multi-rate digital signal processing and blocks that increase radio power efficiency by linearizing the power amplifier output stage. The importance of a digital predistortion (DPD) block is emphasized and an adaptive polynomial approach based on cartesian to polar conversion is then proposed. Such radio architecture has successfully been implemented on a low-cost FPGA family meeting the WiMAX/LTE spectrum and Error Vector Magnitude (EVM) requirements.

**Index Terms**—transceivers, digital radio, amplifier distortion.

## I. INTRODUCTION

The deployment of networks which can manage effectively high data-traffic growth rates is a continuous challenge for wireless network operators. Wireless and mobile technology standards are evolving towards higher bandwidth requirements and cell-throughput growth. High data rates over air interface, as well as mobility, are supported by the latest wireless standards, HSPA+, WiMAX and LTE. In the mean time, the spectrum requirements for these standards become stricter. In order to meet the spectrum mask requirements, the development of advanced signal processing techniques becomes essential. [2,5]

The upgrades required to deploy networks based on these standards must balance the limited availability of new spectrum, leverage existing spectrum and ensure operation of all desired standards. The latter must take place during the transition phase, which usually spreads over many years. Distributed open base station architecture concepts (Fig.1) have evolved in parallel with the evolution of standards targeting a flexible, cost-efficient and more scalable modular environment for managing radio access. In particular, the Open Base Station Architecture Initiative (OBSAI) and the Common Public Radio Interface (CPRI) introduced

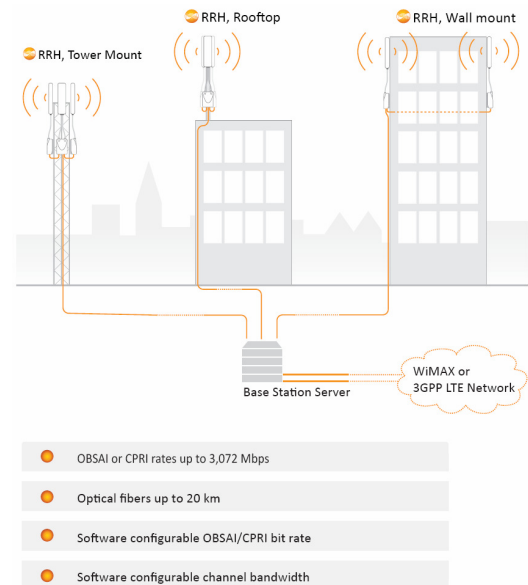


Fig. 1 Distributed Wireless Base station system

standardized interfaces separating physically the base station server from the radio module (remote radio head concept).

## II. SYSTEM ARCHITECTURE AND REQUIREMENTS

Architectures based on remote radio heads are driven by the operators' need to reduce the capital expenditure (CAPEX) and operational expenditure (OPEX). Figure 2 illustrates an architecture where a 2G/3G/4G basestation is connected to remote radio heads over optical fibers. Either CPRI or OBSAI interfacing standards may be used as transport protocols to carry baseband data to the radio and cover a three-sector cell.

A remote radio head incorporates a large number of digital interfacing and processing functions as depicted in Figure 3. However, in general these blocks do not depend on the nature of the baseband data to be transmitted. The remote radio head remains transparent and suitable for multimode broadband communication.

The key advantages of separating the baseband module from the radio module are listed in Table 1. The most recent OFDMA-based standards WiMAX and LTE include up to 20MHz wideband radio channels for Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) operational modes.

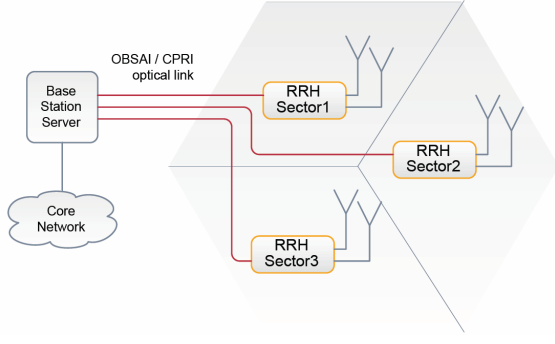


Fig. 2 Three-sector wireless call using remote radio heads

TABLE I  
ADVANTAGES OF REMOTE RADIO HEADS

<b>Flexibility in software</b>	Remote upgrades and frequency-agile operations, configuration and management via IP protocols (Telnet, FTP, SNMP, XML/SOAP over UDPCP)
<b>Higher performance</b>	High power efficiency, efficient use of spectrum, high Rx sensitivity
<b>Multi-mode operations</b>	Combined and concurrent multi-standard operations reduce need for new equipment
<b>Flexible multi-carrier capability</b>	Frequency agility, easier capacity upgrades
<b>Smaller footprint</b>	Easier installation, reduced wind load, lower site rental costs, optimized coverage

### III. MULTI-RATE BLOCKS FOR REMOTE RADIO HEADS

The objective is having a flexible radio module supporting multiple radio channel bandwidths (WiMAX 3.5/5/7/8.75/10/20MHz and LTE 2.5/5/10/15/20MHz) in the same radio platform implementation, using only pure software reconfiguration to switch between them. Moreover, another challenge is to support multiple carriers assigned to the same channel in a multi-carrier fashioned system. To achieve this, the designer has to select between using a different clock domain for each rate or using one single-clock domain with specialized DSP blocks that enable software flexibility. The single-clock domain technique using DSP blocks is more elegant. Its advantage is that it can efficiently convert any sample rate into a common system rate lowering the design complexity. The sampling rate conversion (SRC) is achieved with Farrow filters that can efficiently implement arbitrary resampling. These are optimized for highest performance as well as low logical resources consumption. When these are combined with multi-channel digital upconversion (DUC) or digital downconversion (DDC) in the uplink direction case, they enable multiple sample rates to be processed concurrently and in the same clock domain of the digital-to-analog converter (DAC) or analog-to-digital converter (ADC). In this way, this method enables flexibility by supporting both

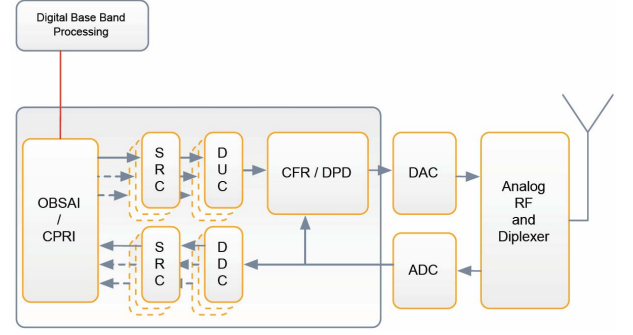


Fig. 3 Remote radio head system architecture

single-clock and multiple-clock techniques.

For example, the typical sample rate for a 10MHz channel bandwidth of a WiMAX OFDMA signal is 11.2MHz. Using a sampling rate converter the sample rate can reach 122.88MHz with noise added by sampling kept below 74dB. For an LTE signal of 10MHz, the sample rate will be 15.36MHz and the SRC will require only a software reconfiguration of the filter coefficients for the given conversion ratio. This shows an example of the SRC approach advantage in such applications.

### IV. DIGITAL PREDISTORTION BLOCK

#### A. Importance of digital predistortion

The existing radio modules for high speed digital systems used in wireless communications include non-linear components in their transmit chain, such as power amplifiers. Introducing non-linearities result in poor spectrum efficiency as well as limited output power. Poor spectrum efficiency can be described as inband interference and introduced outband noise because of intermodulation products [2, 6]. In Wimax and LTE applications compliance with specific spectrum masks is compulsory due to the fact that interference from transmissions in neighbor frequencies can be the dominating source of radio-link impairment. Achieving the latter, presupposes a power amplifier that is capable of delivering a constant gain across different input power levels and operation time. However, power amplifiers are not always set to operate in their linear region. On the contrary, they are set to operate close to their non-linear saturation point in order to increase output power.

Inevitably, techniques to cancel out the non-linearities have to be applied. Different approaches have been proposed for different frequency ranges, baseband frequencies, intermediate frequencies and radio frequencies. In this paper the approach followed is a polynomial digital predistortion in the intermediate frequency. This technique is applied on a radio module assuming that the baseband data have been received from the baseband module and have been digitally upconverted prior the block of common system IF.

The predistortion block follows the fundamental concept of predistorting the signal before amplification with the

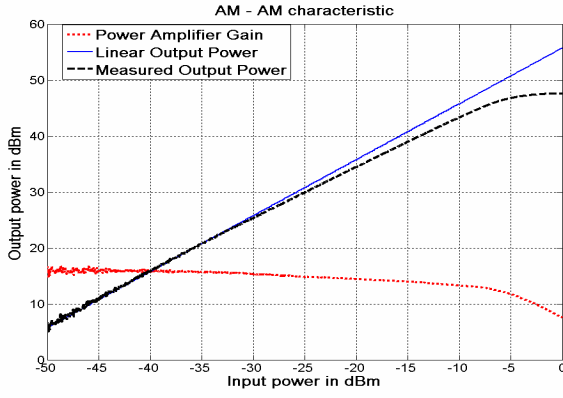


Fig. 4 Input power Vs output power for GaN power amplifier

inverse characteristics of the distortion that the RF power amplifier will introduce. In this way, we achieve the objective that is to amplify the input signal in a linear way (constant gain). At the same time, the design is concentrated on achieving acceptable intermodulation products of 3<sup>rd</sup> and 5<sup>th</sup> order providing the required spectrum efficiency without interfering with other bands.

#### B. RF Power Amplifier Characterization

The first step is to characterize the specific power amplifier of our system. In our case the RF power amplifier consists of GaN transistors that can deliver on average 4Watts (36dBm) of output power. Transistors such as gallium nitride high electron mobility transistors (GaN HEMTs) have been recently introduced commercially. These transistors have numerous electrical advantages over other types of transistors and can be operated over wide bandwidths. These attributes along with high efficiency and linearity under OFDM modulation make these devices ideal for broadband wireless access.

For obtaining the model of the GaN amplifier a network analyzer was used. The transfer characteristic of the amplifier was measured by performing power sweeps of both single tone and multi tone signals for further accuracy [7, 8]. More precisely for the multitone case we had 64 tones equally spaced at 10.94 kHz, resembling the spacing used in OFDM subcarriers in Wimax. Sampling frequency was 150MHz. The input power levels varied from -75dBm to 10dBm with a step of 5dBm for low power levels (-75 dBm to -35 dBm) and step of 1dBm for the rest of the power levels. The outcome is an AM-AM characterization graph (Fig.4), showing the correspondence between input power and output power deviation as well as and an AM-PM characterization graph, showing the correspondence between input power and phase shift (Fig.5). Moreover, we can also notice that the gain does not remain constant as in theory but decreases when the RF power amplifier reaches the saturation point of operation.

#### C. DPD System Block Description

The proposed system for implementing a DPD engine is depicted in figure 6. It is part of a complete radio frequency

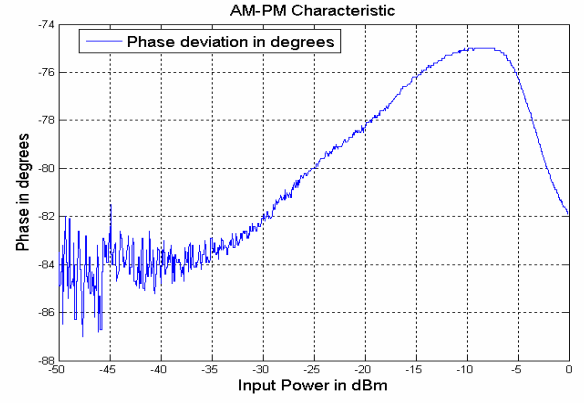


Fig. 5 Input power Vs phase deviation for GaN power amplifier

module and has been implemented on a low-cost FPGA for enabling flexibility and maintaining reasonable cost-points for commercial applications. Most of proposed systems present impressive simulation results [3] but lack investigation as far as the actual hardware implementation is concerned since they are mainly research driven rather than commercially oriented. The overall goal of this work was to implement a highly flexible and optimized system compliant to WiMAX/LTE radio standards performances. One of the major challenges was to be able to fit the DPD engine within a low-cost FPGA family, which was constrained by logical resources availability (amount of logical elements, dedicated multipliers blocks and embedded memory blocks) along with all the rest of the existing radio processing block functions as illustrated in Fig. 3. In fact, the memory and timing constraint requirements for adaptive algorithms are high due to fact that an accurate synchronization of data between feedforward/feedback data is essential. Our approach is based on approximating the PA's transfer function using a polynomial and predistorting the input data in the inverse way. The polynomial selected is a 5<sup>th</sup> order polynomial. Higher polynomials would increase complexity and hardware usage of our design. A 5<sup>th</sup> order polynomial applied to both amplitude and phase was considered sufficient to provide the necessary margin to comply with WiMAX/LTE spectrum masks.

In our example the input signal to the system is a baseband OFDM signal of 10MHz channel bandwidth. The input signal is first fed to the predistorter where the cartesian to polar transformation takes place. The reason this conversion is necessary is because in this way we can treat amplitude and phase independently. Thus, the AM-AM and AM-PM characteristics that were calculated for the power amplifier can be directly imposed on amplitude and phase. In case of cartesian format the calculation of either I or Q vector is dependent on the phase. A small miscalculation or lack of precision in any of AM-AM or AM-PM characteristic functions on an actual hardware implementation may result in incorrect data predistortion. Consequently, the spectrum will not be utilized efficiently and the error vector magnitude (EVM) will increase. In fact, the latter two criteria are the

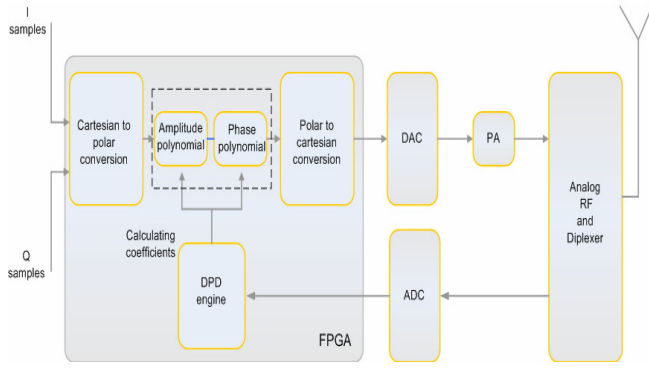


Fig. 6 Proposed DPD block

most essential for the performance of the RF transmit chain.

Predistorted data have to be transformed back to cartesian format from polar since the input to the digital-to-analog converter (DAC) is I and Q vectors. The DAC output is in IF frequency and is finally upconverted to the 2.5GHz band by the analog RF unit. On the opposite direction, the power amplifier output is feeding a down-conversion stage (from RF 2.5GHz to IF) before entering the analog-to-digital converter (ADC). In case of TDD applications, the feedback path is time-shared with the receive path and is used in combination with the predistorter to calculate the coefficients of the polynomial. This polynomial attempts to approximate the inverse characteristic of the GaN power amplifier. The least means squared algorithm (LMS) is used to minimize the error by adjusting the polynomial coefficients accordingly [5, 9].

We can see the improvement in power spectrum after using a 5<sup>th</sup> order polynomial to approximate the power amplifier's inverse transfer function in figure 7. With red color we illustrate the spectrum mask applicable to TDD base stations and TDD user equipment respectively for mobile broadband data transmission systems operating in the 2.5/2.6GHz band. In this way, the limits for essential parameters such as emission mask, output power, spurious emission are specified. We notice that we achieve a 12dB decrease in the outband frequencies which offer a considerable margin for spectrum compliance. In the mean time, the EVM is 1.8%, which is lower than the WiMAX and LTE compliance threshold. (Mobile WiMAX threshold: 3%, LTE threshold: 8%)

## V. CONCLUSIONS

This paper presented a complete digital architecture of an advanced multimode radio suitable for commercial wireless, mobile broadband communications. Because of the strict spectrum requirements imposed by the spectral regulation bodies for modern high data rate wireless networks, the use of a digital predistortion block has become a necessity. An adaptive polynomial approach for linearizing the RF power amplifier has been designed and implemented on a low-cost FPGA overcoming the challenges imposed by logical size of the design and the timing constraints on the feedback path.

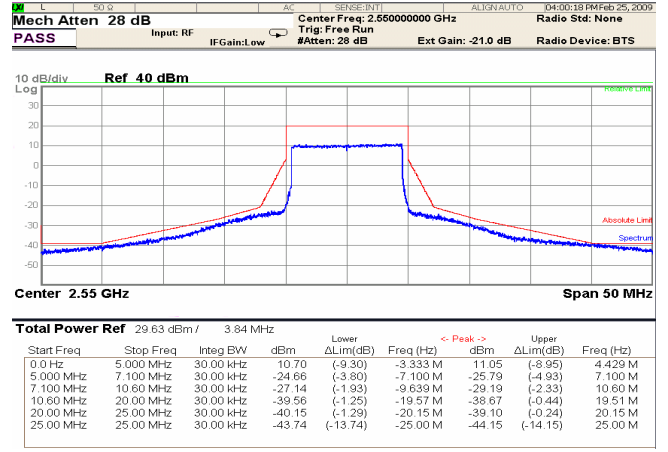


Fig. 7 Measurement results with 10MHz OFDMA WiMAX signal

The decrease achieved for the spectrum emission was in average 12dB and the EVM level was kept below 1.8%. The advanced digital radio architecture that has been proposed in this paper is implementable in an existing hardware environment and provides a flexible software configurable multimode radio solution complying with 4G oriented wireless radio standards.

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